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REPRODUCTIVE STRATEGIES IN A POPULATION OF *GOBIOSOMA BOSCI* (OSTEICHTHYES: GOBIIDAE) WITH SLOW AND FAST MATURING INDIVIDUALS

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ABSTRACT The reproductive biology of *Gobiosoma bosci* collected from November 1986 to October 1987 in the McFaddin Wildlife Refuge in southeast Texas was studied by using morphometric data. Males achieved greater weights per unit length than females, and longevity was about 12 to 13 months. GSI values and mean monthly ovum diameters indicated that the breeding season ran from April to September, with a major activity peak in May and a minor peak in September. Significant differences in male and female standard lengths (SL), ovum diameter, and egg number existed for sexually mature specimens between the first and second peaks of reproductive activity. An egg versus length analysis produced a positive linear relationship. An accessory gonadal structure index (ASGI) was developed and revealed that maximal AGS development corresponded with the male GSI, but did not produce discernable peaks. Two reproductive strategies were followed and depended upon time of hatching and growth rate. Some individuals that hatched early in the breeding season grew rapidly and were capable of egg laying by August or September. Individuals hatched late in the breeding season delayed breeding until the following season.

Introduction

The distribution of the naked goby, *Gobiosoma bosci*, extends from Long Island, New York, to the state of Campeche, Mexico (Hoese and Moore 1977). In view of the marked environmental differences throughout its range, *G. bosci* may be expected to vary its reproductive strategies. In a review of life history phenomena, Cole (1954) stated that the age at which reproduction begins is one of the most significant characteristics, and as such will influence the reproductive success of an individual. Therefore, southerly populations of *G. bosci* have at least two potential reproductive strategies available to them (Stearns and Crandall 1984). First, an individual may grow throughout the non-reproductive season after hatching and then engage in breeding during the subsequent breeding season. Alternatively, young-of-the-year may grow rapidly enough to reproduce before the end of the breeding season, and thereby gain a breeding season not available to fish with delayed breeding. As such, individuals within the same population may employ one strategy or the other depending upon their time of hatching and environmental conditions.

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Gobiosoma bosci, a cavity nester preferring hard substrates (Bechler et al. 1990), has been studied extensively along the Atlantic Coast. Dahlberg and Conyers (1973), who reviewed much of the literature, postulated that spawning seasons for different populations of *G. bosci* were variable, and depended on location. They related initiation and termination of spawning to water temperature and indicated peak spawning activity was in the warmest months, May through August. However, they did not discuss any variations in breeding strategies. Other reports on *G. bosci* by Nero (1976), Crabtree and Middaugh (1982), and Fitzsimons and Seok (1989) revealed many facts about the life history and ecology of *G. bosci*. However, none of the above studies examined reproductive strategies of the naked goby in detail along the Gulf Coast. In this study, we concentrated specifically on life history data related to the reproductive biology of *G. bosci* in a southeast Texas salt marsh.

Description of the Study Area

The McFaddin National Wildlife Refuge is located in southern Jefferson County, 20 km southwest of Sabine Pass, Texas (Griffith and Bechler 1995), a subtropical to temperate region of the United States. The refuge is a brackish marsh dissected by meandering creeks, man-made cuts, and shallow lakes; the largest, Clam Lake, was the primary site of this study.

Clam Lake is relatively shallow, 1.0 to 1.3 m in depth, with the deepest area 2.8 m. The substrate and banks along the edges of the lake consist of a firm clay. A fine silt substrate lies 1 to 5 m from shore. The clay banks are riddled with holes and tunnels inhabited by *Rhithropanopeus harrisi*, the mud crab, two species of *Uca*, the fiddler crabs, and *Callinectes sapidus*, the blue crab. The predominant flora surrounding the lake is *Phragmites australis*, a reed grass, and *Spartina alterniflora*, a salt marsh grass. Tidal influences in Clam Lake are minimal. Wind-generated wave action undercuts the banks of the lake and results in the gradual erosion of the shoreline and a subsequent exposure of roots of *Phragmites* and *Spartina*. These roots are washed free of soil and extend into the water except during drought and low tide. Large clumps of *Phragmites* roots break off and fall into the water. These remained close to the banks of the lake below the water and provided habitat for *G. bosci*.

METHODS AND MATERIALS

Beginning in November 1986, monthly collections of *G. bosci* were made in Clam Lake for a period of 12 months, except for July, when no collection was made. Sixty to 100 fish were collected each month by using a 3.23 mm mesh seine. Specimens were hardened in 10% formalin for 24 hours, washed in water for 24 hours, and preserved in 55% isopropyl alcohol. A minimum of 28 specimens (14 males, 14 females) were examined from each monthly collection. Standard length (SL) was measured to the nearest 0.01 mm with a Mitutoyo dial caliper. Total body weight was measured to the nearest 0.0001 g with a Mettler AE 100 analytical balance. Gonads were removed and wet weighed together as a unit for use in obtaining Gonadal Somatic Indices (GSI). Ten accessory gonadal structures (AGS), which are related to sexual maturation of male gobies (Miller 1984, Cole and Robertson, 1988, Lahnsteiner et al. 1992), were removed and wet weighed each month. The weight of the AGS was divided by the total wet body weight and multiplied by 100 to produce an Accessory Gonadal Structure Index (AGSI) similar to that of the GSI. In females, 10 ova centrally located on the surface of the ovary and randomly selected were measured in 10 animals each month with an ocular micrometer. During the months of April and May, the beginning of the breeding season, the diameters of 175 to 200 ova on the surface of the ovaries were measured in six fish to determine if more than one size class of ova were present. Eggs large enough to be teased from the ovaries were counted by hand with an Olympus zoom stereo microscope system. These ova were classified as to their developmental stage by following Heins and Rabito (1986). Salinity and water temperature were taken each month with a Yellow Springs TSC meter. All statistical analyses employed MINITAB (1986) software.

RESULTS

General Ecology

Salinity during the year in which the fish were collected ranged from 0 to 12 ppt. Water temperature ranged from 7 to 32°C. During the months of highest reproductive activity, April to June, salinity varied from 2 to 6 ppt and mean water temperature was 28°C. Day length increased from 12.48 hours on 1 April 1987 to 14.05 hours on 30 June 1987 (United States Naval Observatory 1965). In September, when there was a smaller peak in reproductive activity, the salinity was 12 ppt and water temperature was 28°C. Day length decreased from 12.81 hours on 1 September 1987 to 11.90 hours on 30 September 1987.

Specimens for preservation were collected in clam shells, algal mats, grass clumps, and *Phragmites australis* roots along the edge of the lake. Seining over soft sediments produced few specimens compared to the number collected close to the banks.

Life History

Length-frequency relationships examined by month indicated that *G. bosci* life expectancy was not more than 12 to 13 months (Figure 1). This conclusion was based on the fact that during the months of August and September specimens greater than 25 and 29 mm respectively were not collected. However, from November to June individuals exceeding 29 mm (range=30.0-44.4 mm) were common.

A broad range of size classes from December to April indicated that *G. bosci* most likely reproduced throughout the spring and summer. The smallest specimens (minimum=11.1 mm) were collected from August to October and represented offspring newly recruited into the population during late spring and summer. The maximum size of specimens progressively increased from October to April when a maximum size of 44.4 mm was reached. From April to June, the beginning of the reproductive season as discussed below, the size of *G. bosci* decreased from the maximum to 40.0 mm (Figure 1). The maximum size of *G. bosci* in August was 24.8 mm, in September, 29.7 mm, and in October, 36.6 mm. The increase in maximum size between each pair of consecutive months was 4.9 mm and 6.9 mm with an average of 5.9 mm/month. Thus if a growth rate of approximately 6 mm/month through the summer is assumed, the largest individuals in August would be no more than about four months old. These fish indicate that all gobies collected in this month represented a new generation.

Length-weight relationships comparing males and females showed that males not only reached a greater maximum standard length (44.4 mm) than females (34.7 mm), but were heavier per unit body length (Figure 2). A curvilinear relationship between standard length and weight existed for males and females. The regression analysis produced the following equations:

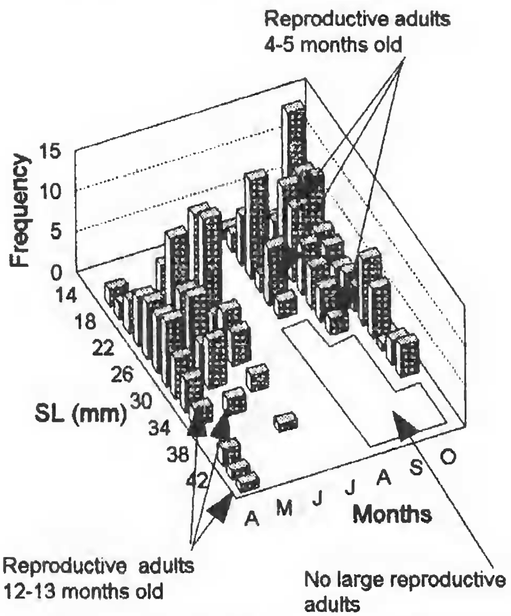

Figure 1. Length-frequency histogram for the months involved in the breeding season of *G. bosci* in the McFaddin National Wildlife Refuge, Sabine Pass, TX. Size class increments are based on 2 mm intervals. Data for the month of July are missing. The month of October is given for size comparisons, but is not part of the breeding season.

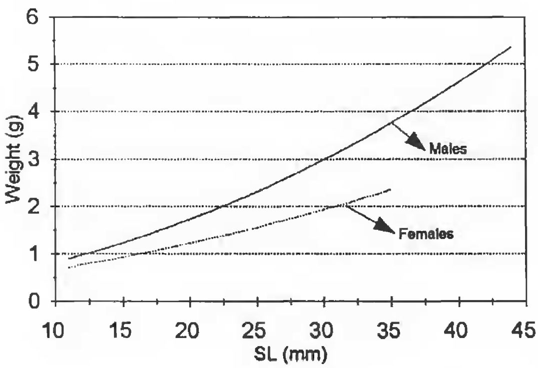

Figure 2. Length-weight relationships for male and female *G. bosci* are given. The 367 data points used to compute the regression lines are not shown.

$$\text{Weight}_{males} = 0.281 + 0.0364SL + 0.0018SL2$$
$$\text{Weight}_{females} = 0.291 + 0.0309SL + 0.0008SL2$$

These two regression models were significantly different (N=367; R^2=0.958; DF=3, 363; F=6.1891; P<0.005) and showed that males were heavier than females per unit length. The results of t-tests indicate that the quadratic (t=-4.03, P<0.01) and linear (t=-3.27, P<0.01) components were responsible for the differences between the models.

Ova easily teased from the ovaries were classified as mature to ripe (Heins and Rabito 1986). Mean number of mature to ripe ova per female was 466 (N=40, SD=178.2) with a range of 116 to 1030. These ova made up two distinct size classes in each of six females examined from April and May (Figure 3).

Mean diameter for all stages of developing ova in May was 0.45 mm (N=12, SD=0.1153). The September mean ovum diameter was much lower, 0.19 mm, but the variance greater (N=8, SD=0.1538). Mean ovum diameter of mature and ripening eggs in April and May was 0.49 mm (range: 0.35 to 0.56 mm) and, in September, 0.42 mm (range: 0.34 to 0.50 mm). A two sample t-test showed a significant difference in the diameter of mature and ripening ova for the two periods (N=23; t=2.75; DF=21; P=0.012).

Not only were ovum diameters smaller during the second breeding peak, but ovum number per female was also significantly lower (N=29: DF=3, 25: R^2=0.73; F=22.42; P=0.0001). A regression analysis comparing egg number versus SL for females from April and May against females from August and September produced the following models:

$$\text{Eggs}_{peak\ 1} = -577 + 45.4SL$$
$$\text{Eggs}_{peak\ 2} = -382 + 34.0SL$$

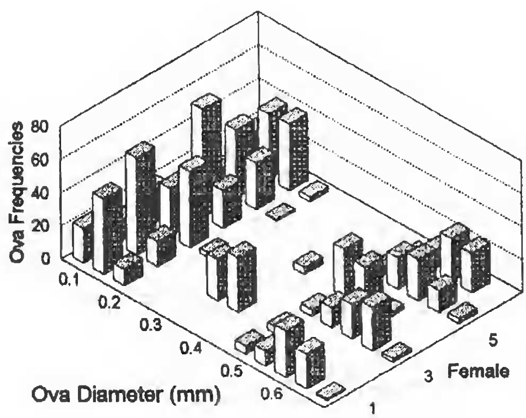

Figure 3. Ovum size class frequencies for six females collected in April and May. Size class increments are based on 0.05 mm intervals.

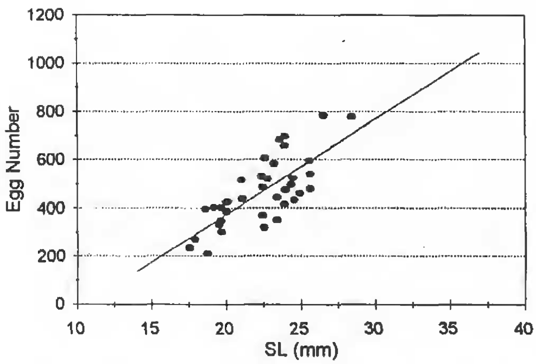

Figure 4. Linear relationship between SL and egg number for all females collected during the breeding season in the McFaddin National Wildlife Refuge, Sabine Pass, TX.

The difference between the two models resulted from significant differences in the coefficients of the slopes (t=2.22, P=0.036), but not in the intercepts (t=0.51, P=0.617). The mean egg number during the first peak was 505 (SD=137.1) and 252 (SD=95.2) during the second peak.

The total number of maturing to ripe ova in the ovaries of all females produced the following regression model (Figure 4):

Fecundity = -416 + 39.5SL

The positive correlation between SL and ova number was significant (N=37; DF=1, 35; F=45.836; $P<0.001$; R^2=0.567).

Mean male GSI values were low from November to January, began to rise in February and March, and peaked in April (Figure 5). GSI values then declined slightly during June, produced a second peak in August, and then declined in September. The April peak had a mean value of 1.266 and the August peak a mean of 1.284. Male GSI values peaked one month prior to the female peak GSI values for both reproductive periods.

Female GSI values showed a bimodal distribution, but with a more dramatic change than males (Figure 5). Female GSI values remained low November through December, began a gradual increase in January, increased rapidly February through April, and peaked in May at a mean value of 14.26. GSI values declined in August, peaked again in September at a mean value of 4.10 and declined in October.

In male *G. bosci* the AGS was mitten-shaped with a small lobe extending lateral to the main lobe, attached to the body wall near the vent, and extended dorsally between the inner body wall and the intestinal tract. Each AGS was attached to the caudal end of the testis by a small duct. During December the AGS were small and difficult to locate and remove. In months of high reproductive activity, the AGS were large and completely filled the ventral portion of the abdominal cavity.

AGSI values (Figure 5) followed a pattern similar to GSI values for males. AGSI values were low November through December and rose slowly from January to March. Unlike GSI values however, AGSI values did not peak in April but continued to climb and peaked in May, remained high through August, and then declined until October.

Ovarian maturation in female *G. bosci* was determined by ovum diameter. Mean ovum diameters (Figure 6) remained low October through February, and then began to increase in March. The increase in ovum diameter in March signaled the onset of ovum maturation. Therefore, the mean ovum diameter for March was used as a criterion against which ovum diameters for fish examined in other months were compared. All females whose mean ovum diameter was larger than 0.1924 mm, the mean ovum diameter for March, were considered to possess maturing ova.

Of 32 females examined in August and September, 13 had a mean ovum diameter greater than 0.1924 mm, the minimum mean size of maturing ova. The mean SL of these 13 females was 20.8 mm (range=16.9 to 24.0 mm). Of the 40 fish examined in April and May, 31 had ovum diameters exceeding 0.1924 mm. The mean standard length of these 31 females was 24.1 mm (range=18.9 mm to 29.6 mm). A comparison of SL indicated that sexually mature females from August and September were significantly shorter than females from April and May (N=22; DF=20; t=4.92; P=0.0001). In addition, significantly fewer females possessed maturing ovaries during the second breeding peak (N=32, DF=1, X^2=24.953, $P<0.001$).

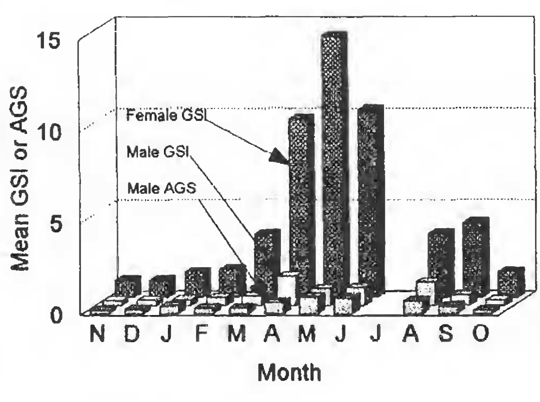

Figure 5. Monthly mean GSI and AGS values for males and females. Data for the month of July are not given.

Male sexual maturity was determined on the basis of GSI values (Figure 5). GSI values, which began increasing in March, were used as an indicator of maturing testes (N=16, $\bar{x}$=0.5624). Of 23 males examined in April, 20 had a GSI exceeding 0.5624. The mean SL of these 20 males was 30.6 mm (range: 19.5 to 44.4 mm). GSI also peaked in August. Mean SL of males with a GSI value above 0.5624 was 20.5 mm (range: 17.3 to 24.6 mm). A two sample t-test comparing maturing males from each time period indicated that males matured at a shorter SL in the late summer (N=61; DF=56.9; t=6.10; P=0.0001).

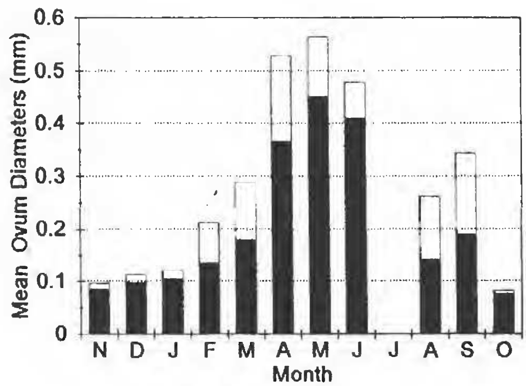

Figure 6. Monthly mean ovum diameters. Data for the month of July are not given. Open portions of bars represent standard deviations.

DISCUSSION

According to conclusions by Dahlberg and Conyers (1973), populations of *G. bosci* in the northern parts of its range should reproduce late in life after having grown and matured over the winter. Populations at the southern end of the range, such as in south Florida and Mexico, would be expected to mature earlier and possibly at a smaller size during the protracted breeding season. The primary factor controlling the age at first reproduction, and thus the reproductive tactic employed by an individual, would be the length of the breeding season in combination with the time of hatching.

The onset of the reproductive season in the Clam Lake population of *G. bosci*, determined by changes in GSI and AGSI values, and ovum diameters, indicated the following: (1) the reproductive season extended from at least late April to September, a period of five to six months; (2) the reproductive season possessed bimodal peaks in spawning activity; (3) the presence of mature and ripening ova from April to September indicated that breeding occurred throughout the summer; and (4) individual females possessed multiple size classes of ova suggesting that they might breed more than once during the season, a fact supported by field experiments (Conn 1989).

Individuals involved in the first reproductive peak in May were significantly larger than those in the September peak. The absence of large individuals in the last half of the summer indicated that the oldest individuals were not living more than 12 to 13 months and were dying out by August. Therefore, at least some individuals involved in the second breeding peak had hatched out during the early part of the breeding season, matured rapidly, and were breeding by the end of the breeding season. Among these individuals, only 40.6% produced eggs capable of being ovulated and laid, and indicating that the majority of individuals did not reproduce until the following spring.

From this analysis we conclude that individual members of the *G. bosci* population in Clam Lake followed two distinct reproductive strategies based upon their time of hatching. Some individuals that hatched early in the breeding season matured rapidly, reproduced at the end of the breeding season, and laid a low number of eggs. These same individuals then had the opportunity for further growth over the winter with a second opportunity to produce a greater number of eggs in the early part of the next breeding season. Individuals hatched later in the reproductive season were too small to reproduce by the end of the season and delayed breeding until the following year. These conclusions support Stearns and Crandall (1984) and Stearns and Koella (1986), who found that plasticity in reproductive strategies allows individuals to vary their age and size at first reproduction. Our data also indicate that time of hatching is a critical factor in determining which reproductive strategy individual *G. bosci* employ in protracted breeding seasons.

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LITERATURE CITED

Bechler, D.L., C.H. Conn, and T.S. Ling. 1990. A novel nest-trap for ecological and behavioral studies of cavity-nesting fishes. J Fish Biol 36:277-278.

Cole, K.S. and D.R. Robertson. 1988. Protogyny in the Caribbean reef goby, *Coryphopterus personatus*: gonad ontogeny and social influences on sex-change. Bull Mar Sci 42:317-333.

Cole, L.C. 1954. The population consequences of life history phenomena. Quart Rev Biol 29:103-137.

Conn, C.H. 1989. The reproductive behavior of *Gobiosoma bosci*, the naked goby. [Unpublished masters thesis] Department of Biology, Lamar University, TX. 50 p.

Crabtree, R.E. and Middaugh. 1982. Oyster shell size and the selection of spawning sites of *Chasmodes bosquianus*, *Hypleurochilus germinatus*, *Hypsoblennuis ionthas* (Pisces, Blenniidae) and *Gobiosoma bosci* (Pisces, Gobiidae) in two South Carolina estuaries. Estuaries 5:150-155.

Dahlberg, M.D. and J.C. Conyers. 1973. An ecological study of *Gobiosoma bosci* and *G. ginsburgi* (Pisces, Gobiidae) on the Georgia coast. Fish Bull 71:279-287.

Fitsimons, J.M. and K. Seok. 1989. The effect of size, sex, prior residency, and past experience on territorial defense by the naked goby, *Gobiosoma bosci*. Proc Louisiana Acad Sci 52:35-42.

Griffith, S.A and D.L. Bechler. 1995. The distribution and abundance of the bay anchovy, *Anchoa mitchilli*, in a Southeast Texas Marsh Lake System. Gulf Res Rep 9:117-122.

Hiens, D.C. and F.G. Rabito, Jr. 1986. Spawning performance in North American minnows: direct evidence of the occurrence of multiple clutches in the genus *Notropis*. J Fish Biol 28:343-357.

Hoese, H.D. and R.H. Moore. 1977. Fishes of the Gulf of Mexico. Texas A&M University Press, College Station. 327 p.

Lahnsteiner, F., M. Seiwald, and R.A. Patzner. 1992. The seminal vesicles of the male grass goby *Zosterisessor ophiocephalus* (Teleostei, Gobiidae). Fine structure and histochemistry. Zoomorphology 111:239-248.

Miller, P.J. 1984. The Tokology of Gobioid Fishes. Pages 119-153 in G.W. Potts and R.J. Wootton, eds. Fish reproduction, strategies and tactics. Academic Press Inc., London.

MINITAB, Inc. 1986. Minitab Reference Manual, 5th release. State College, Pa. 236 p.

Nero, L.L. 1976. The natural history of the naked goby, *Gobiosoma bosci* (Perciformes: Gobiidae). [Unpublished masters thesis] Department of Biology, Old Dominion University, VA. 86 p.

Stearns, S.C. and R.E. Crandall. 1984. Plasticity for age and size at sexual maturity: A life-history response to unavoidable stress. In: Potts, G.W. and R.J. Wootton (eds), Fish Reproduction, Strategies and Tactics, p 13-33. Academic Press, New York.

Stearns, S.C. and J.C. Koella. 1986. The evolution of phenotypic plasticity in life-history traits: prediction of reaction norms for age and size at maturity. Evolution 40:893-913.